

Strength and durability of backfill geogrid reinforcement for retaining walls

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ABSTRACT: The durability and degradation of two types of geogrids: High Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET) was studied, using accelerated exposure, with super-ambient temperatures for different simulated exposure conditions, and soil-water related to the soil conditions in Florida. The temperatures were 35° C, 50° C, and 65° C, with submergence in the following groundwater-simulating solutions: Calcareous (pH 9.0), phosphate (pH 4.5), limerock and seawater, and freshwater for PET specimens only. The immersion periods were 30 days, 60 days, 90 days, 120 days, 365 days, and 417 days. Regression analysis was carried out to process the data. Long term performance at ambient temperatures was extrapolated, based on the Arrhenius method. The durability curves showed that the effect of degradation in HDPE geogrids is very small for up to 10,000 hours. This results indicate excellent performance of HDPE geogrids in the solutions to which they were exposed. The PET geogrids showed a small degradation, mainly for the 65° C. The variation in degradation between the different solutions was minimal, indicating hydrolysis as the main cause. The findings will enable reliable life cycle analysis of geogrids based on durability.

1 INTRODUCTION

Geogrids are polymeric geosynthetics designed specifically to provide soil reinforcement. A positive connection between the two components of the mechanically stabilized earth (MSE) structure is created by the three-dimensional open structure of geogrids, which interlocks with the surrounding soil. This bonding between soil and the reinforcement creates a more efficient, cost effective structure. The main polymers currently used for reinforcement include polypropylene (PP), polyester terephthalate (PET), and polyethylene (PE). Geogrids were first introduced into North America in the early 1980's. The ASTM D5262 (1992) standards define a geogrid as a planar structure formed by a regular network of tensile elements, with apertures of sufficient size to allow interlocking with the surrounding soil, earth, rock, or any geotechnical material to perform the functions of reinforcement and/or segregation. Geogrids are produced for biaxial and uniaxial load-carrying configurations.

Due to the relatively short experience with these polymeric materials, there are uncertainties regarding their durability, with respect to retainment of the design properties after being subjected to construction stresses and exposed to in-soil environments over the expected design life. Potential degradation of polymeric reinforcement, with time, will depend on the characteristics of a specific polymer, configuration, and the environment to which it is exposed. This dictates the need for more research in this area. If geogrids have to be used as an alternative to steel reinforcement to

overcome the corrosion problem, their performance has to be established based on laboratory and field testing for site specific conditions, e.g. high water tables and temperatures ranging between 27° C to 38° C in Florida.

1.1 HDPE Geogrids

HDPE is the acronym for High Density Polyethylene, The uniaxial HDPE geogrids used in this research are manufactured by stretching a punched sheet of extruded HDPE in one direction, under carefully controlled conditions. This process aligns the polymer's long-chain molecules in the direction of drawing, and results in a product with high one-directional tensile strength and modulus.

1.2 PET Geogrids

PET is the acronym for Polyester Terephthalate. PET geogrids are made of polyester multifilament yarns, which are interlocked by weaving to create a stable network, such that the yarns retain their relative position. Compared to HDPE, PET is more flexible in bending and exhibits a relatively lower junction strength.

1.3 Durability and Degradation

Moisture absorption is associated with: a) plasticization and, b) hydrolysis. Water does not cause significant hydrolysis without other environmental factors, such as the presence of specific catalytic ions or elevated temperatures. The presence of specific catalytic ions, as well as pH, can influence the rate of hydrolysis. Temperature may affect the hydrolysis reaction in two different ways: a) the rate of diffusion of water is a function of temperature, and b) the hydrolysis reaction follows the Arrhenius Law, i.e., the reaction rate increases and decreases exponentially with temperature variations. Typical soil temperatures are in the range of 10 to 15.6° C; temperatures near the surface of the wall can reach 29° C to 38° C. The pH values of various MSE materials used by the Florida Department of Transportation are in the range of 4.5 to 9.

However, the degree of moisture absorbed and the processes of degradation vary for different polymers. HDPE has almost no affinity to water. Hydrolysis occurs when water molecules react with the polymer molecules. This results in chain scission, reduced molecular weight, and strength loss. Hydrolysis is the very slow inverse reaction of the synthesis of PET, when water is present. The chemical environment is an important aging factor, especially considering the aggressive environment that can be formed in the soil. The principal mechanisms of chemical degradation have been defined as follows Van Zanten, (1986):

Metathesis - breaking of carbon - carbon bonds.

Solvolysis - breaking of carbon - noncarbon bonds in the amorphous (liquid).

Oxidation - liquid reaction with molecular oxygen.

Dissolution- separation into component molecules by solution.

Each of these mechanisms leads to bond breakage at the molecular level, which is called bond-cism. If these mechanisms occur under stress, environmental stress cracking (ESC) will occur.

1.4 Arrhenius Method

In 1886, Arrhenius formulated an expression for the relationship between temperature and the rate of degradation. Equation 1 gives the Arrhenius equation, Koerner (1998):

$$\frac{r_{T_{test}}}{r_{T_{site}}} = e^{-\left(\frac{E_{act}}{R}\left(\frac{1}{T_{test}} - \frac{1}{T_{site}}\right)\right)} \quad (1)$$

where E_{act}/R = slope of Arrhenius plot; T_{test} = incubated (high) temperature, in °K; T_{site} = site-specific (lower) temperature, in °K; r = reaction time; E_{act} = effective activation energy, J/mole, and R = universal gas constant, 8.314 J/mole

Eqn. 1 can also be written as follows:

$$\ln\left(\frac{r_{T_{test}}}{r_{T_{site}}}\right) = \left(\frac{E_{act}}{R}\right)\left(\frac{1}{T_{test}} - \frac{1}{T_{site}}\right) \quad (2)$$

or

$$\frac{E_{act}}{R} = \frac{\ln\left(\frac{1}{t_1}\right) - \ln\left(\frac{1}{t_2}\right)}{\left(\frac{1}{T_1}\right) - \left(\frac{1}{T_2}\right)} \quad (3)$$

where t = time, hour, and, T = temperature, °K

In the Arrhenius plot, the degradation is plotted as the logarithm of the reciprocal of time versus the reciprocal of temperature. From this the slope of the Arrhenius plot can be obtained using equation (3). A schematic of the Arrhenius plot is given in Figure 1.

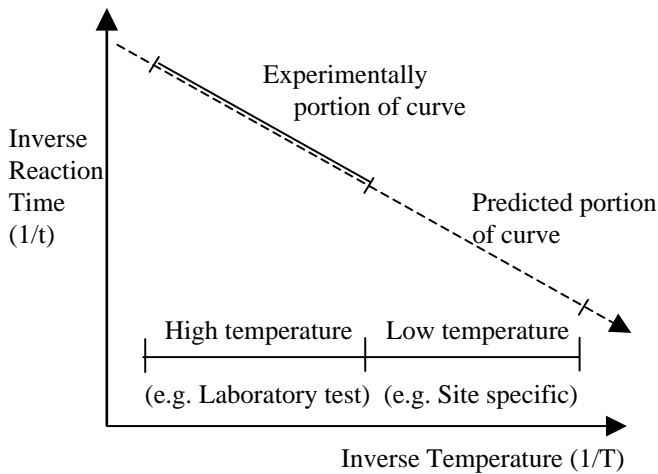


Figure 1. Generalized Arrhenius plot, for a specified stress. Ahn et al, (1998)

In this model, the temperature has an exponential effect on the time required for a specific level of degradation.

2 EXPERIMENTAL INVESTIGATION

To evaluate the long-term durability and degradation behavior, accelerated exposures were used, with super-ambient temperatures for different simulated exposure conditions, and soil water related to the soil conditions in Florida. The temperatures used were 35° C, 50° C, and 65° C, with submergence in the following groundwater-simulating solutions:

HDPE specimens:

- Calcareous (pH 9.0)
- Phosphate (pH 4.5)
- Limerock
- Seawater

PET specimens

- Calcareous (pH 9.0)
- Phosphate (pH 4.5)
- Limerock
- Seawater
- Freshwater

The immersion periods were 30 days, 60 days, 90 days, 120 days, 365 days, and 417 days.

The ultimate strength was measured by single strip tension testing, based on the modified wide-width strip method (ASTM D4595), to reduce the amount of space and load needed due to the large number of specimens .

The ultimate strengths were compared with those for unexposed specimens. Particular attention was focussed on the degradation of PET specimens due to hydrolysis. Comparison of the ultimate strengths of PET specimens, immersed in water, with those for the unexposed ones, enabled the evaluation of the strength loss due to hydrolysis associated with moisture and temperature. The specimens, immersed in chemical solutions, also enabled the evaluation of the effect of high pH on hydrolysis.

Typical durability curves for HDPE and PET are presented in Figures 2 and 3. It can be observed that the degradation in the HDPE specimens was small; some of the durability curves even showed an increase in strength at the 65 °C temperature.

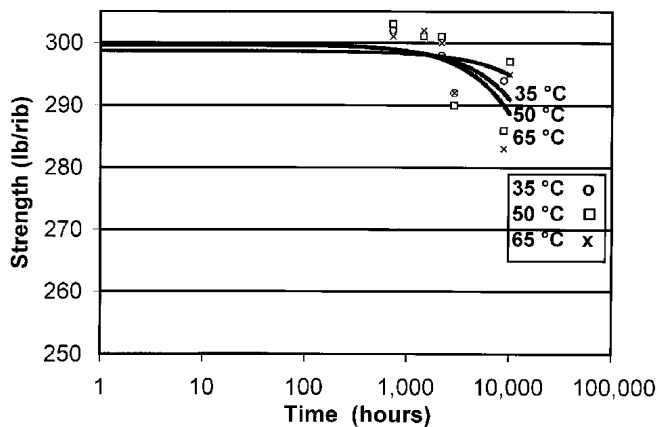


Figure 2. Durability curves for HDPE geogrids in calcareous solution.

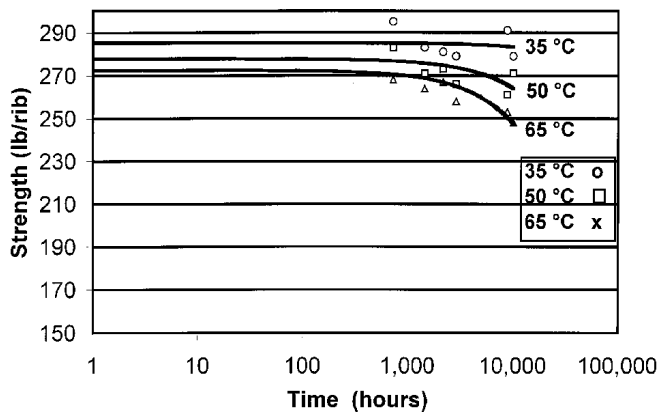


Figure 3. Durability curves for PET geogrids in phosphate solution.

This shows that the effect of environmental exposure on the HDPE geogrids is negligible. PET specimens showed some degradation, which seemed to be very similar for the different solutions, indicating hydrolysis as the main cause.

Curves for the other environmental exposures were similar to the ones shown. It can be noticed that there is a large variability from specimen to specimen for the PET geogrids. This variability is greater than the differences due to the exposures.

Figures 4 and 5 curves show the property retained values for HDPE in Seawater and PET in limerock solution. It can be seen that HDPE basically retains the whole property, while for PET specimens there is some small loss.

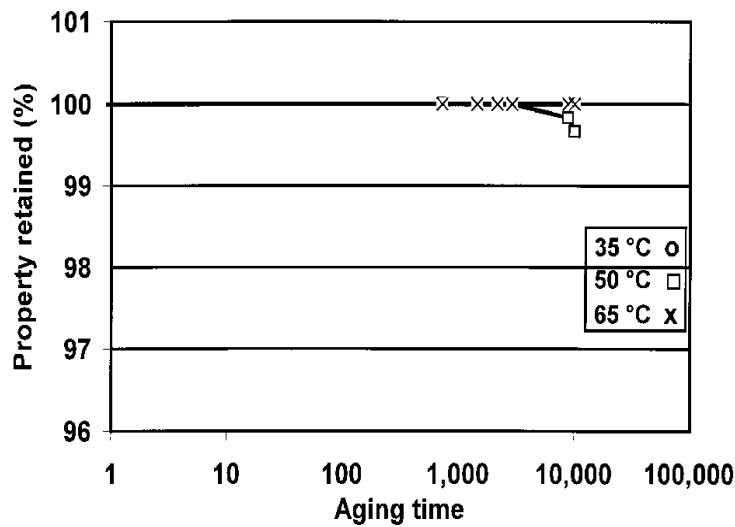


Figure 4. Property-retained curves for HDPE geogrids in seawater.

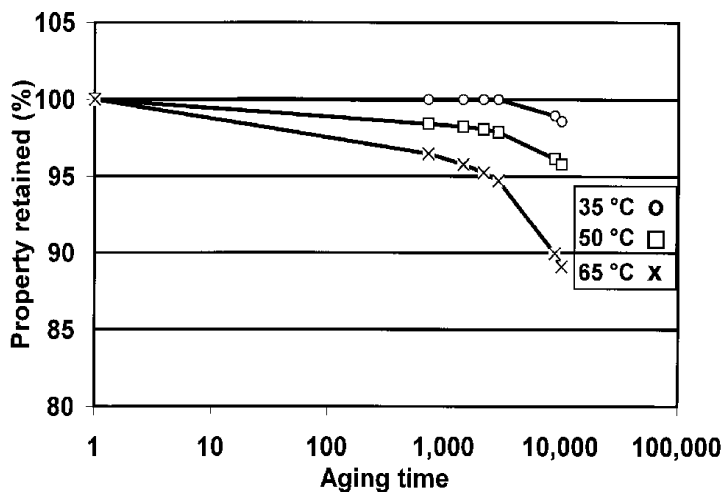


Figure 5. Property-retained curves for PET geogrids in limerock.

The Arrhenius curves, presented in Figures 6 to 9, were constructed for 99% of property retained for HDPE and PET geogrids, and for 97% and 95% for PET.

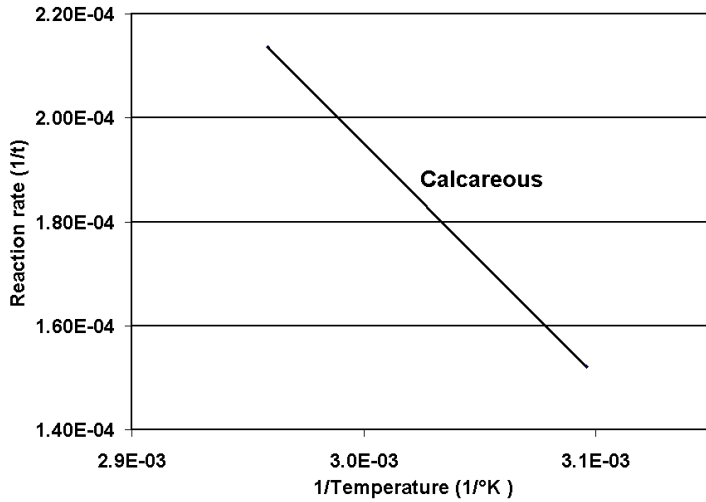


Figure 6. Arrhenius curves for 99% of property retained for HDPE geogrids

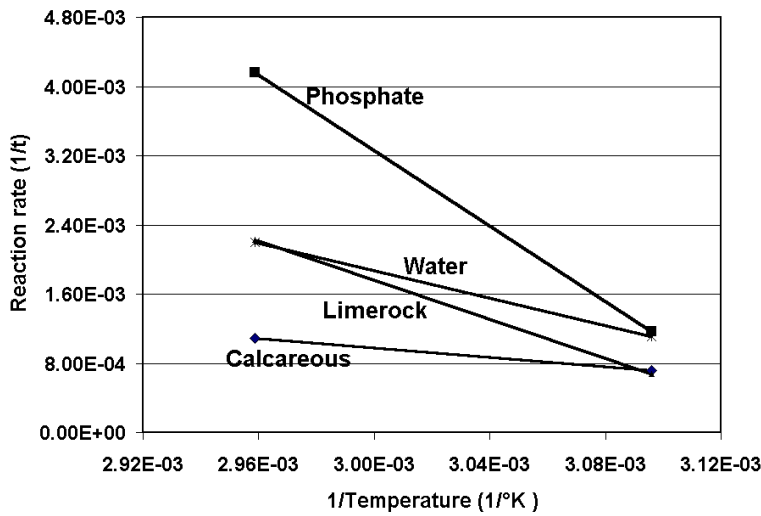


Figure 7. Arrhenius curves for 99% of property retained for PET geogrids.

In Figure 6 only the curve for HDPE geogrids subjected to calcareous exposure is presented for 99% property retained since is the only one with enough data due to the small degradation of HDPE. In Figure 7 the Arrhenius curves are presented for PET geogrids in all the exposures, except seawater, for which the 50° C exposure showed an increase in property retained and the 35° C exposure did not reach 99% of property retained in 10,000 hours.

The same was the case for the curves for 97% of property retained. Also, for the calcareous exposure at 50° C the property retained did not reach 95%.

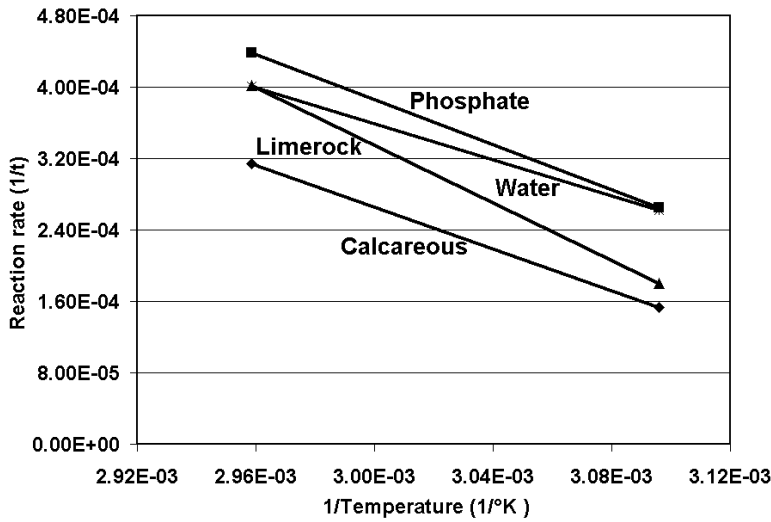


Figure 8. Arrhenius curves for 97% of property retained for PET geogrids.

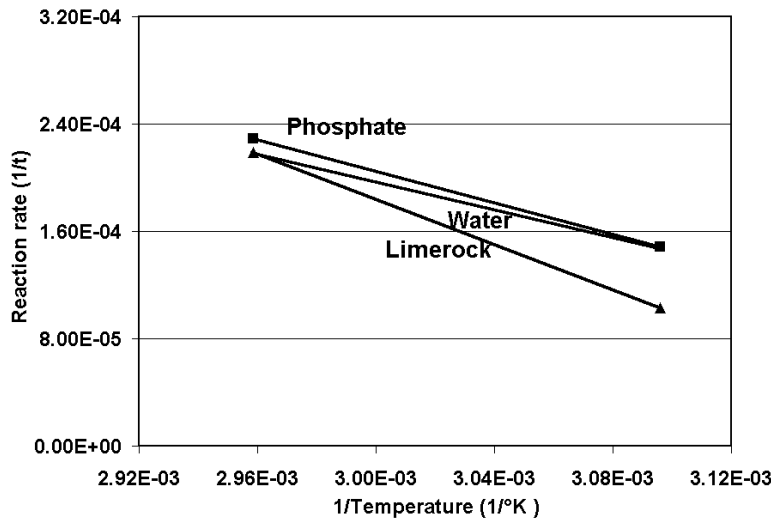


Figure 9. Arrhenius curves for 95% of property retained for PET geogrids.

All the Arrhenius curves were plotted using only the data for 55° C and 65° C temperatures, since for 35° C the degradation was minimal in all cases and did not even reach the 99% property retained.

The results from the Arrhenius modeling are presented in Tables 1 and 2. For the HDPE geogrids in Table 1 only the calcareous exposure is presented for 99% property retained since is the only one with enough data due to the small degradation of HDPE. For PET specimens only the seawater did not provide enough data for 99 and 97% property retained. The same was the case for seawater and calcareous solutions with 95% property retained.

Table 1. Predicted time to reach 99% of original strength for HDPE geogrids

Solution	99% property retained Years
Calcareous	1.6

Table 2. Predicted time to reach 99%,97% and 95% of original strength for PET geogrids

Solution	99% property retained Years	97% property retained Years	95% property retained Years
Calcareous	0.4	3.9	
Phosphate	1.8	1.4	2.1
Limerock	2.6	4.1	6.3
Water	0.5	1.2	1.9

Results obtained seem adequate, except for phosphate exposure, for which the 97% degradation seemed to occur before the 99%. This is because the property retained curve for 65° C crosses basically the 99 and 97% of property retained simultaneously.

3 CONCLUSIONS

Large variabilities of the data were encountered, this is attributed to the testing of single rib specimens. The variability in the specimens is greater in the PET geogrids. After regression analysis it can be seen that the effect of degradation in HDPE geogrids is negligible for up to 10,000 hours for seawater and limerock, for the calcareous (pH 9.0), and phosphate (pH 4.5) exposures, a negligible degradation was observed at 10,000 hours with the maximum degradation of 3% for the calcareous solution. For 35° C, the degradation was less than 1% in any exposure. These results indicate excellent performance of HDPE geogrids in the solutions to which they were exposed.

The PET geogrids showed a small degradation, mainly for the 65° C. The variation in degradation between the different solutions was minimal indicating hydrolysis as the main cause. The maximum degradation was 13.3% for the Phosphate solution at 65° C, but the maximum at 35° C for the limerock exposure was only 1.2%. This indicates that hydrolysis is the main cause, since the amounts of degradation do not vary uniformly in the different exposures, and hydrolysis is accelerated by elevated temperatures.

The Arrhenius method is not precise for small degradations; for the HDPE specimens, the Arrhenius method for 99% property retained, or 1% degradation, could be applied only to the calcareous exposure, since it was the only exposure with 65° C and the 55° C, that crossed the 99% property retained, as none of the exposures at 35° C crossed the 99% property retained.

For the PET specimens, for 99% property retained the Arrhenius method could be applied to all the exposures except seawater, for which the 55° C curve did not cross the 99% property retained. For 97%, the same applied, and for 95%, the calcareous exposure at 50° C, also, did not reach 1% degradation. For HDPE, none of the 35° C curves crossed the 99% property retained or 1% degradation.

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